Global Energy and Water Cycles

The abundance of water in all three phases (solid, liquid, vapor) makes the Earth unique in the Solar System. Knowledge of the fluxes and changes of phase of water are essential for an understanding of weather, climate and, indeed, of life itself.

Global Energy and Water Cycles provides a state-of-the-art treatment of advances in our understanding through improvements in global models, in the representation of the processes included in the models, and in related observations. It deals with fluxes within the atmosphere, at and beneath the land and ocean surface, and the interaction between them. This area of environmental science is developing rapidly and it is important to remain in touch with related developments across the wide range of the meteorological, hydrologic and oceanographic topics involved. In order to provide authoritative coverage, the book draws upon the expertise of many of the world's leading researchers. It provides a comprehensive treatment of a subject which is currently scattered through the literature, and therefore makes it accessible as a coherent whole for the first time.

The book will be of main interest to graduate students and researchers in meteorology, hydrology and oceanography, but it will also appeal to final-year undergraduates in these subjects.

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Preface

There is a growing realization that new global problems, faced both by scientists and by citizens, can only be tackled adequately by new partnerships formed for this purpose. Within science itself, new partnerships are needed to understand the complex scientific realities that underlie these global problems. The development of a comprehensive description of the climate system is an activity that takes the combined efforts of meteorologists, hydrologists, oceanographers and others. A particularly important part of this is the description of global energy and water cycles.

The World Climate Research Programme (WCRP), following the innovative pattern of its predecessor, the Global Atmospheric Research Programme (GARP), is an example of successful partnership and cooperation between the independent scientific community represented by the International Council of Scientific Unions and the intergovernmental community represented by the World Meteorological Organization, a specialized agency of the United Nations.

Part of the WCRP is the Global Energy and Water Cycle Experiment (GEWEX). The problems facing the GEWEX project, the state of our present knowledge, the progress to date, and the key problems that remain – all these were well exposed in the presentations and discussions at the GEWEX Conference held at the Royal Society in London in July 1994. This conference was successful in encouraging real dialogue between experts in different specialisms. This volume is not a volume of proceedings, but is based in part on contributions to that conference, and builds upon it. This book gives the opportunity of extending this important exchange of results and opinions to a wider audience, and brings together the state of our knowledge in this important area. The scientific community are in debt to the editors and contributors for the energy and judgement they have shown throughout this enterprise.

J. Dooge

Foreword

GEWEX: the international context of this book

Striking advances were made in the 1970s in observing the general circulation of the atmosphere and modeling its dynamics, thus developing the relatively new field of *geophysical fluid dynamics* into an effective tool for planetary-scale weather forecasting. However, using the words of Richard P. Feynman, these advances were limited to studying the 'flow of dry water' – a mathematical abstraction in which energy sources and sinks could be largely ignored or very much simplified. The performance of existing general circulation models (GCMs) and computers, as well as the limitations of the observing systems of the time, effectively precluded investigating the diabatic processes which drive the global atmosphere, land surface hydrology and the world ocean circulation.

Nevertheless, environmental scientists understood very well that the great machine which determines the Earth climate and had maintained conditions favorable to life on our planet for billions of years, depends on the operation of a wide range of *physical, geochemical and biological processes*. They recognized that climate was primarily controlled by radiation transfer through the clear air of the stratosphere as well as the cloudy, wet air of the troposphere. They knew that rainfall was controlled by the transport of atmospheric water vapor and the dynamics of clouds. They understood that water resources depended upon rain, groundwater storage and river discharge as well as evapotranspiration and vegetal life.

Indeed, in the 1970s and early 1980s, scientists in all branches of environmental research had already made considerably progress in the study of these various processes individually. For example, a strong radiation science community was actively investigating radiative transfer through clear air and aerosols from satellites or aircraft. Cloud physicists were busy studying the dynamics and microphysical constitution of rain clouds. Agrometeorologists were building the scientific foundations for a quantitative understanding of land surface and vegetation processes in hydrology, while professional hydrologists themselves were far along building 'conceptual models' of water storage and discharge in river catchments.

However, these scientific investigations were largely discipline oriented and piecemeal. It was difficult to see how the patchwork of individual process studies could be transmuted into a comprehensive description of the interactive Earth system. Atmospheric and climate modelers were not interested because their fluid-dynamical models did not allow enough scope for such complicated physics. Observational scientists were not interested because reliable global climatological records of such exotic properties as energy and water fluxes were non-existent.

Yet, the portents of future advances were already in evidence, based as it is often the case upon *technical breakthroughs* such as dramatic advances in computer performance and new concepts for Earth observation from space. From its inception, the

World Climate Research Programme (WCRP) was steered toward a scientific exploitation of these new tools. Climate researchers pressed the atmospheric modelers to consider the thermodynamics as well as the pure dynamics of the atmospheric circulation, and to free themselves from the specified surface boundary conditions and initial value problems that are the hallmark of weather forecasting. Simultaneously, the planners of WCRP sought the support of science-funding and space research agencies to promote essential new instrument technologies and climatologically relevant space missions.

A most significant achievement in this period was the success of the multi-satellite Earth Radiation Budget Experiment (ERBE), which effectively appeared as the crowning achievement of a long series of space research projects to monitor the Earth radiation balance from space. For the first time, it was possible to obtain a quantitative assessment of the contribution of water vapor to the greenhouse effect of clear air, as well as the radiative forcing of clouds. Yet, monitoring radiation fluxes at the top of the atmosphere could not suffice in order to understand climate phenomena and the sensitivity of climate to external forcing: it was clearly necessary to probe into the wet and cloudy troposphere, the deep ocean and the soil on continental surfaces. New active microwave sensors that could penetrate rain clouds, as well as non-precipitating but optically thick clouds, were under development and would obviously constitute a major step in this direction.

At the same time, a new generation of climate models and climate change simulations provided both the means and the incentive to incorporate more realistic formulations of energetic and hydrologic processes. Radiation and clouds, water vapor transport and rain, evaporation from the ocean and land, groundwater storage and river flow, were indeed recognized as components of a single interactive system. The time was right to take one more step in the direction of *integrated earth system sciences* and promote a more active dialogue between scientific disciplines that were close enough and mature enough to benefit from such interactions.

It was also very timely, especially from the perspective of planning space missions and other long-term research initiatives, to formulate a unifying scientific strategy for addressing the global energy balance and hydrologic cycle. The Global Energy and Water Cycle Experiment (GEWEX) is the planetary-scale environmental research program formulated by WCRP in the late 1980s to fulfill these requirements. The present book deals with our current understanding of the related science.

P. Morel

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